Yield variability in *Phalaris canariensis* L. due to seeding date, seeding rate and nitrogen fertilizer

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May, W. E., Lafond, G. P., Gan, Y. T., Hucl, P., Holzapfel, C. B., Johnston, A. M. and Stevenson, C. 2012. **Yield variability in *Phalaris canariensis* L. due to seeding date, seeding rate and nitrogen fertilizer**. Can. J. Plant Sci. **92**: 651–669. Concern over the year-to-year and field-to-field variability in grain yield has consistently been expressed by annual canarygrass growers in Saskatchewan. The objectives of these studies were to understand the effects of a delayed seeding date (0, 15, 30 and 45 d), seeding rate (15, 25, 35, 45, and 55 kg ha^{-1} of seed) and applied N fertilizer (20, 40, 60, 80, and 100 kg N ha^{-1}) on the development and yield of annual canarygrass, to improve recommendations of best management practices in annual canarygrass and to determine the impact of these factors on yield variability in annual canarygrass. To address these objectives, three single factor field experiments were conducted, at a number of sites in Saskatchewan from 1998 to 2001. Seeding date had a large effect on grain yield. Grain yield decreased as seeding was delayed by 30 and 45 d from early May. Seeding rate had a small effect on grain yield. The response curve was very shallow peaking at approximately 1310 kg ha^{-1} at a seeding rate of 45 kg ha^{-1}. Variation in grain yield tended to decrease as the seeding rate increased. There was a small increase in grain yield with the addition of nitrogen fertilizer. The response curve estimated a maximum yield of 1215 kg ha^{-1}, which was obtained with a nitrogen rate of 78 kg ha^{-1}. The majority of the increase was between 20 and 40 kg N ha^{-1}, with a 2.3 kg ha^{-1} increase in grain yield for each kg of fertilizer N in that range of rates. There was a slight increase in grain yield as the nitrogen rate increased above 40 kg ha^{-1} but the variation in grain yield also increased reducing the incentive for growers to use N rates above 40 kg ha^{-1}. Seeding date had a large effect on seed yield and could impact yield variability while seeding rate and nitrogen rate did not have a large effect on seed yield or yield variability.

Key words: Canaryseed, environmental conditions, grain yield, yield stability

May, W. E., Lafond, G. P., Gan, Y. T., Hucl, P., Holzapfel, C. B., Johnston, A. M. et Stevenson, C. 2012. **Variabilité du rendement de *Phalaris canariensis* L. selon la date des semis, la densité de semis et l'application d'engrais azotés**. Can. J. Plant Sci. **92**: 651–669. De nombreux producteurs d'alpiste roseau annuel de la Saskatchewan s'inquiètent de la variabilité du rendement grainier de cette culture d'une année et d'un champ à l'autre. Les études entreprises par les auteurs devaient préciser les conséquences d'un retard des semis (0, 15, 30 ou 45 jours), de la densité de semis (15, 25, 35, 45 ou 55 kg de semences par hectare) et de la quantité d'engrais appliquée (20, 40, 60, 80 ou 100 kg de N par hectare) sur le développement et sur le rendement de l'alpiste roseau annuel, cela dans le but d'améliorer les recommandations concernant les meilleurs pratiques agronomiques pour cette culture ainsi que pour déterminer l'impact de ces paramètres sur la variabilité du rendement. À cette fin, ils ont procédé à trois expériences unifactorielles sur le terrain, à divers endroits de la Saskatchewan, de 1998 à 2001. La date des semis influe considérablement sur le rendement grainier, qui diminue lorsque les semis sont reportés de 30 ou de 45 jours à partir du début du mois de mai. La densité de semis affecte légèrement le rendement. La courbe de réponse présente un très petit pic autour de 1 310 kg par hectare, environ, à la densité de semis de 45 kg par hectare. La variation du rendement grainier a tendance à s'atténuer quand la densité de semis augmente. Le rendement grainier s'accroît légèrement avec l'application d'engrais azotés. La courbe de réponse laisse entrevoir un rendement maximal de 1 215 kg par hectare lorsqu'on applique 78 kg d'engrais azoté par hectare; la majeure partie de cette hausse survient entre l'application de 20 à 40 kg de N par hectare, chaque kilo d'engrais ajouté entraînant une hausse de 2,3 kg par hectare du rendement grainier, dans cette fourchette. Le rendement grainier augmente légèrement lorsque le taux d'application des engrais dépasse 40 kg par hectare, mais sa variation incite aussi moins les agriculteurs à appliquer au-delà de 40 kg de N par hectare aux cultures. La date des semis a une forte incidence sur le rendement grainier et pourrait modifier la variabilité du rendement, mais la densité de semis et le taux d'application des engrais azotés n'agissent pas énormément sur le rendement grainier ni sur la variabilité du rendement.

Mots clés: Alpiste roseau, conditions environnementales, rendement grainier, stabilité du rendement

Annual canarygrass or canaryseed (*Phalaris canariensis* L.) is a cereal crop whose primary purpose is feed for caged birds. Canada produces approx 69 to 79% of the world's annual canarygrass production. Production in Canada has centred in the province of Saskatchewan (FAOSTAT 2008). Annual canarygrass was first evaluated as a hay crop in 1896 and as a grain crop in 1906 at Indian Head, SK (MacKay 1897, 1907). In Canada, the recording of annual canarygrass production area began in 1971 with 800 ha being seeded. The seeded area in Saskatchewan has ranged from 87 000 to 332 000 ha over the past 20 yr, representing 89 to 98% of the production in Canada (Saskatchewan Ministry of Agriculture 2009). Most annual canarygrass grown in Saskatchewan uses a no-till production system. In Saskatchewan, annual canarygrass has become an important alternative cereal crop to durum wheat [*T. turgidum* L. ssp. *durum* (Desf.) Husn.] and spring wheat (*Triticum aestivum* L.). Since it is marketed as a bird feed, crop prices tend to fluctuate independently of spring wheat and durum wheat. Growing annual canarygrass allows growers to diversify their rotation and spread their economic risks.

In an informal survey of annual canarygrass growers in 1997, the greatest concern expressed by growers was the variability in grain yield from field to field and from year to year. Another concern was that annual canarygrass research in Saskatchewan has been limited to one geographic area for each of the experiments conducted with no large multi-site experiments to ensure that the results were applicable over a wide area of the province (Holt and Hunter 1987; Holt 1988, 1989; Miller 2000).

A limited amount of research has been conducted on the effect of seeding date on annual canarygrass. Miller (2000) found that under semi-arid growing conditions, annual canarygrass yield decreased by 29% while barley (*Hordeum vulgare* L.) and spring wheat yields decreased by 14 and 11%, respectively, with delayed seeding from the beginning of May to the end of May. Their 2-yr study experienced terminal drought in both years. The larger reduction in yield of annual canarygrass compared with barley or spring wheat with delayed seeding supports the commonly held view that annual canarygrass does not have as much terminal drought tolerance as spring wheat or barley. In this study by Miller (2000) the yield component most affect by delayed seeding was panicles per square metre with the effects on kernel weight and seeds per panicle being inconsistent. A study conducted in Argentina (Bodega et al. 2003) found a similar trend with yield declining as seeding was delayed. Cogliatti et al. (2011) reported that the ranking of annual canarygrass accessions changed as seeding was delayed from Jul. 21 to Aug. 24 at one location in Argentina. The grain yield of AC Marie did not change as seeding was delayed. Information is lacking on the effect of seeding date on annual canarygrass over wide geographic areas, especially the area in which a large portion of the world's canaryseed is grown. When producers know the likely yield loss due to delayed seeding it helps them to arrange the order in which they seed their crops to maximize profit.

Seeding rate has been shown to affect grain yield, crop uniformity, maturity, grain quality and the competitiveness of a crops like barley, oat (*Avena sativa* L.) and pea (*Pisum sativum* L.) to weeds (O'Donovan et al. 1999; Johnston et al. 2002; May et al. 2009b). At Indian Head, SK, Holt (1989) found a small quadratic increase in grain yield as the seeding rate increased from 7.5 to 80 kg ha^{-1} with no change in kernel weight, heading or maturity. This study was conducted under a conventional tillage fallow system. A study in Minnesota found small increases or decreases in grain yield as the seeding rate increased varying by site and year (Putnam et al. 1990). More information about the effects of seeding rate on annual canarygrass production across the growing region of annual canarygrass in western Canada is needed to improve the seeding rate recommended to producers.

Initial fertility recommendations for annual canarygrass in Saskatchewan were based on the recommendations for spring wheat (Slinkard et al. 1991). Holt (1988) found that over 3 yr in a sub-humid environment, grain yield response was maximized with 50 to and 75 kg N ha^{-1}. In addition, Holt (1988) found that increasing the rate of nitrogen fertilizer increased plant height, decreased test weight and had no effect on kernel weight. Other research conducted in Minnesota's portion of the Red River Valley found very little response in grain yield to applied nitrogen fertilizer and based fertility recommendations on soil organic matter content (Putnam et al. 1990). More information is also required to better understand the response of annual canarygrass to fertilizer N and to improve fertilizer N recommendations to producers.

The objectives of this study were to get a better understanding of the effects of seeding date, seeding rate and N fertilizer on annual canarygrass production across the major agro-ecological zones of Saskatchewan, to improve the recommendations given to farmers on seeding date, seeding rate and nitrogen fertilizer rate, and to determine if one or more of these factors might help explain the observed yield variability in annual canarygrass.

MATERIALS AND METHODS

Three field experiments were conducted at six sites in Saskatchewan (Indian Head, Weyburn, Saskatoon, Melfort, Swift Current and Stewart Valley) over a 4-yr period (1998 to 2001). Not all experiments were conducted at every site in each year (Table 1). The soil types were Indian Head heavy clay at Indian Head, Regina heavy clay at Weyburn, Sutherland clay at Saskatoon, Melfort silty clay loam at Melfort, Swinton Silt Loam at Swift Current and Sceptre heavy clay at Steward Valley. These sites are located in or close to the regions where annual canarygrass is currently grown in

Table 1. Locations for the three experiments

Location/year	Experiment: Seeding date	Seeding rate	Nitrogen rate
Indian Head (IH)			
1998	x[z]	x	x
1999	x	x	x
2000	x	x	x
2001	x	x	x
Weyburn (Wey)			
1998		x	x
1999		x	x
2000		x	x
2001		x	x
Melfort (Mel)			
1999	x		x
2000	x	x	
2001	x	x	
Saskatoon (Sas)			
1999	x		
2000	x		
2001	x		
Swift Current (SC)			
1999	x		
2000	x		
2001	x		
Stewart Valley (SV)			
1999		x	x
2000			x
2001			x

[z]x represents a location and year when the experiment was conducted.

Saskatchewan. All three experiments were single factor experiments conducted as a randomized complete block design with four replications. The seeding date experiment had four seeding dates, early May, mid-May, early June and mid-June, except at Swift Current where all the seeding dates were shifted earlier by approximately 15 d. The target dates were May 01, May 15, Jun. 01 and Jun. 15. However, due to environmental conditions, seeding did not always occur on these exact dates in all years at all locations. The seeding date was shifted earlier at Swift Current because in that area of the province seeding usually begins in mid-April. The seeding date experiment was conducted at Indian Head, Melfort, Saskatoon and Swift Current (Table 1). The second experiment consists of five seeding rates of 15, 25, 35, 45, and 55 kg ha^{-1} of seed. The third experiment consists of five nitrogen rates of 20, 40, 60, 80, and 100 kg N ha^{-1} using urea as the nitrogen source. The second and third experiments were conducted at Indian Head, Melfort, Weyburn and Stewart Valley (Table 1).

The fertilizer was side banded during seeding at Indian Head, Melfort, Weyburn, Swift Current and Stewart Valley with the fertilizer being placed 3 to 4 cm to the side and 7 cm below the seed. The fertilizer used was a blend of urea, monoammonium phosphate, potassium chloride, and ammonium sulphate. The composition of the blend varied depending on the location in the seeding date and seeding rate experiments and by treatment in the nitrogen rate experiment.

The cultivar CDC Maria (Hucl et al. 2001) was used for all experiments and unless specified, a seeding rate of 35 kg ha^{-1} was used. The row width was 30.48 cm at Indian Head, Weyburn, Saskatoon and Melfort, and 25.4 cm at Swift Current and Stewart Valley. The plot size was 3.7 × 1.2 m at Saskatoon, 15 × 3.0 m at Melfort, 8 × 2 m at Swift Current and Stewart Valley. At Indian Head the plot dimensions were 18.3 × 4.0 in 1998 and 1999, 15.2 × 4.0 m in 2000 and 10.7 × 4.0 m in 2001, while at Weyburn the plots were 15.2 × 4.0 m in 1998, 1999 and 2000, and 10.7 × 4.0 m in 2001. The previous crops were canola (*Brassica napus* L.), flax (*Linum ustitatissimum* L.), canola and canola at Indian Head and Weyburn in 1998, 1999, 2000 and 2001; fallow, chickpea (*Cicer arietinum* L.) and fallow at Swift Current 1999, 2000 and 2001; fallow at Stewart Valley in 1999, 2000 and 2001; canola, canola, and field pea (*Pisum sativum* L.) at Melfort in 1999, 2000 and 2001 and fallow at Saskatoon every year. The plots were managed using a no-till production system except at Saskatoon where tillage was used.

The target level of total nitrogen, a combination of residual soil nitrate (0–60 cm soil layer) and fertilizer nitrogen, was 80 kg ha^{-1} for all sites and this combined rate was used for the seeding date and seeding rate experiment as well. A $NaHCO_3$ extraction procedure (Hamm et al. 1970) was used to estimate residual soil N (NO_3), P, and K. Available S was determined by extraction of 10 g of soil with 50 mL of 0.001 M $CaCl_2$ followed by filtration and determination of S in the filtered extract using a Technicon™ Auto-analyzer II (Hamm et al. 1973).

Phosphorus, potassium and sulphur were applied according to soil test recommendations (ALS Laboratory Services, Saskatoon, SK). Glyphosate was applied before seeding and all in-crop broadleaf herbicide applications were determined separately for each location according to weed species and density using recommended products and rates (Saskatchewan Ministry of Agriculture 2010). The soil residual levels of nitrogen, phosphorus, potassium and sulphur determined in spring prior to seeding are listed in Table 2.

Environmental Conditions

Total monthly precipitation (mm) and mean temperature (°C) data from May to August, and long-term (1971–2000) climatic means, are presented in Table 3 based on data from Environment Canada (2010).

Variables Measured

Plant and Panicle Density

Plant counts were conducted 3 to 5 wk after seeding and annual canarygrass panicles were counted after panicle emergence was complete. Both plants and panicles were measured in two random 1-m sections of crop row

Table 2. Residual nitrogen phosphorus, potassium and sulphur levels at test sites

	Indian Head	Weyburn	Stewart Valley	Swift Current	Saskatoon	Melfort
			($kg\ ha^{-1}$)			
			Nitrogen (0–60 cm)			
1998	27	16	–	–	–	–
1999	46	58	27	44	75	63
2000	20	26	31	9	56	23
2001	45	54	23	48	91	53
			Phosphorus (0–15 cm)			
1998	32	28	–	–	–	–
1999	32	56	9	39	67	38
2000	19	30	34	32	27	27
2001	16.8	34	12	22	35	31
			Potassium (0–15 cm)			
1998	472	531	–	–	–	–
1999	738	790	295	–	674	570
2000	448	607	675	537	593	570
2001	571	573	542	530	570	607
			Sulphur (0–6 cm)			
1998	26	7	–	–	–	–
1999	20	18	75	39	109	61
2000	20	28	17	9	20	68
2001	100	40	93	68	108	65

within each plot and reported as plant numbers per square metre.

Maturity

Physiological maturity was reached when kernel moisture was approximately 30 to 35% and reported as days from seeding.

Lodging

Lodging was rated in each plot at physiological maturity using a 1 to 9 scale (1 = standing, 9 = completely lodged).

Plant Height

Plant height was measured at two places in each plot and reported in centimetres.

Grain Yield

Grain yield was expressed on a clean grain basis with using a 13% kernel moisture content and expressed as kilograms per hectare.

Kernel Weight

Kernel weight, expressed as grams per 1000 seeds, was calculated by weighing 200 kernels in 1998 and 1999, and between 700 and 1000 kernels in 2000 and 2001.

Kernels per Panicle

Kernels per panicle was calculated from the values panicles per square metre, grain yield and kernel weight.

$$\text{Kernels panicle}^{-1} = \text{grain yield (g m}^{-2}\text{)/kernel weight (g)/panicles m}^{-2}$$

Kernels per Unit Area

Kernels per square metre was calculated using grain yield and kernel weight.

$$\text{Kernels m}^{-2} = \text{grain yield (g m}^{-2}\text{)/kernel weight (g).}$$

Test Weight

Test weight was measured using the methods specified by the Canadian Grain Commission's Official Grain Grading Guide (2006) and expressed as g 0.5 L^{-1}.

Statistical Analysis

The analysis of data from each of the three experiments was conducted separately using a random coefficient model with the PROC MIXED procedure of SAS software (Littell et al. 2006). The data from all sites (location by year combinations) was used for the analysis. The advantage of this analysis over a more conventional regression is that random variation across sites and reps can be modeled.

The effects of seeding date, seeding rate, and fertilizer N rate were considered as regressors for the analysis of data for each experiment. The regressor (linear slope coefficient), square of the regressor (quadratic slope coefficient), and the corresponding intercept coefficient were modeled as both fixed and random effects. This regression allowed us to assess average performance and

Table 3. Summary of climatic conditions for selected experimental sites in Saskatchewan in 1998–2001

	Precipitation					Temperature				
	May	June	July	August		May	June	July	August	
Location/year	(mm)				% of long-term average	(°C)				% of long-term average
Indian Head										
1998	49	173	22	39	111	12	13	18	19	98
1999	67	116	84	88	139	11	15	15	17	92
2000	68	105	46	63	111	10	13	18	16	90
2001	21	28	42	12	40	11	15	18	19	100
30-yr average	56	79	67	53		11	16	18	18	
Weyburn										
1998	24	133	66	53	116	13	15	20	21	105
1999	112	73	71	25	119	11	16	18	19	97
2000	103	102	95	57	151	12	14	20	19	98
2001	22	63	82	2	71	13	16	20	21	106
30-yr average	54	73	64	46		12	17	19	18	
Melfort										
1999	42	57	57	36	78	10	15	16	17	97
2000	43	74	106	47	110	9	13	18	17	95
2001	12	20	46	11	36	12	14	19	19	107
30-yr average	46	66	76	57		11	16	17	16	
Saskatoon										
1999	39	64	86	41	110	11	15	17	19	97
2000	49	82	53	22	99	11	15	19	18	98
2001	24	32	48	7	53	13	16	20	21	109
30-yr average	49	61	60	39		12	16	18	18	
Swift Current										
1999	90	84	55	15	117	10	14	16	19	94
2000	65	47	127	13	121	11	14	19	18	98
2001	23	28	63	3	56	12	15	20	21	108
30-yr average	50	66	52	40		11	16	18	18	
Stewart Valley										
1999	105	82	101	30	126	11	15	17	19	95
2000	58	63	119	20	103	12	14	20	19	100
2001	40	32	89	2	64	13	16	20	21	108
30 yr average	56	76	69	52		12	16	19	18	

variability. The variance estimates (random effect) for the intercept and slope coefficients were estimated across sites using a unstructured covariance structure (Littell et al. 2006). Random variation for the quadratic slope coefficient was not modeled for the seeding rate and N fertilizer rate experiments because of very small variance estimates or model instability. Best linear unbiased predictor (BLUP) deviations for the intercept and slope coefficients at each site from the overall intercept and linear or quadratic slope coefficients were used to further explore variability among sites (Littell et al. 2006). Regression coefficients and corresponding variance estimates were declared significant at $P<0.05$.

A grouping methodology, as previously described by Francis and Kannenberg (1978), was used to further explore treatment responses for data from each of the three experiments. The mean and coefficient of variation (CV) were estimated for each treatment combination across sites and replicates. Means were plotted against CV for each level of the treatment, and the overall mean of the treatments means and CVs was included in the plot to categorize the data biplot ordination area into four quadrants/categories: Group I: High mean, low variability (optimal); Group II: High mean, high variability; Group III: Low mean, high variability (poor); and Group IV: Low mean, low variability.

RESULTS AND DISCUSSION

Environmental Conditions

Precipitation was at least 10% above the 30-yr long-term average in 1998 and 1999 at all locations except for Melfort in 1999, which had only 78% (Table 3). In 2000, four of the locations were greater than 10% above the long-term average, while Saskatoon and Stewart Valley were near the long-term average. In 2001, all sites were below the long-term average, ranging from 36% at Melfort to 71% at Weyburn. The long-term average for the growing season temperature never varied by more than 10% from the long-term average at any location in any year.

Residual Soil Nutrients at the Test Sites

The residual nitrogen between a depth of 0 and 60 cm ranged from 9 to 91 kg ha^{-1} across the test sites while phosphorus levels in the soil ranged from 9 to 67 kg ha^{-1} in a soil depth of 0 to 15 cm (Table 2). Potassium in a soil depth of 0 to 15 cm ranged from 295 to 790 kg ha^{-1} and sulphur in a soil depth of 0 to 60 cm ranged from 9 to 109 kg ha^{-1}.

Seeding Date

The intercepts, linear coefficients and quadratic coefficients, and their statistical significance are presented in Figs. 1 and 2, and Table 4. These coefficients, quantify the response of the measured variables to seeding rate (i.e., panicles m^{-2} = intercept + (linear coefficient × days delayed) + (quadratic coefficient × days delayed^2). The intercept coefficients were statistically significant for all measured variables (Fig. 1). A significant intercept indicates that at the first seeding date the measured variable response was greater than zero. In addition, a significant site × intercept interaction indicates that the intercept at one or more sites differed from the overall intercept (Table 4); in this study the site × intercept interaction was significant for all the variables except panicle density.

Plant density was not affected by seeding date (Fig. 1). When compared with the overall intercept of 273 plants m^{-2}, plant density was lower at Swift Current and Melfort in 2000 and Indian Head in 2001 and higher at Melfort in 2001 (Fig. 1). In Fig. 1 the bars under the intercept, linear coefficient, and quadratic coefficient represent the deviation from the overall estimate for an individual site. An asterisk means that the deviation was significant. To derive an intercept or slope coefficient for a specific site you must add the deviation to the corresponding coefficient.

Panicle density had a significant linear response to seeding date with a linear coefficient of -3.59. Panicle density on the first seeding date as predicted by the regression was 566 panicles m^{-2} and decreased as seeding was delayed until the panicle density reach 441 panicles m^{-2} with a 45-d delay in seeding [panicles $m^{-2} = 566 + (-3.59 \times$ days delayed$) + (0.018 \times$ days delayed$^2)$] (Fig 1). This trend was observed by Miller (2000) in Saskatchewan but not by Bodega et al. (2003) in Argentina.

Seed density had a significant quadratic coefficient, -5.247, of the response curve while the linear coefficient was not (Fig. 1). Seed density peaked at 15 925 seeds m^{-2} when seeding was delayed 15 d and declined to 9500 seeds m^{-2} after seeding was delayed for 45 d [seeds $m^{-2} = 15595 + (100.7 \times$ days delayed$) + (-5.247 \times$ days delayed$^2)$ (Fig 1)]. The site × intercept variance estimate corresponded with intercepts that ranged from 27 019 seeds m^{-2} at Saskatoon in 1999 to 7319 seeds m^{-2} at Swift Current in 2001 (Table 4 and Fig. 1). Seed density was higher at Saskatoon in 1999 and at Indian Head in 2000 than the overall average for the first seeding date. Seed density was lower at Swift Current, Saskatoon and Melfort in 2001 than the overall average for the first seeding date. Seed density appears to be sensitive to reduced growing season precipitation on the first seeding date, since these three sites Swift Current, Saskatoon and Melfort in 2001 received below-average precipitation. (Table 3). Interestingly, the two sites with the significantly higher site intercept, Saskatoon in 1999 and Indian Head in 2000, received approximately 110% of the average precipitation for each site, but other sites with larger amounts of precipitation did not have site intercepts that were greater than the intercept from the average of all sites. This suggests that the yield components in annual canarygrass are more sensitive to a lack of water than an abundance of water.

Table 4. Summary of random effect variance estimates for site by intercept, linear, and quadratic slope coefficients quantifying annual canarygrass development and yield responses

Experiment/effect	Plant density	Panicle density	Seed density ($head^{-1}$)	Seed density (m^{-2})	Kernel weight	Grain yield	Lodging	Height	Maturity	Test weight
					Seeding date (Variance estimate)					
Site × Intercept (I)	4128	6856		50.8	0.834	250180		434	121	21.1
Site × Linear (L)	9.740	3.700		0.139	8.1 E–05	519		0.198	0.056	0.007
Site × Quadratic (Q)	0.009	0.002		4.70 E–05	–[z]	0.209		4.74 E–05	4.66 E–05	0
					(Variance estimate *P* value)					
Site × I	0.022	0.051		0.015	0.015	0.01		0.008	0.013	0.014
Site × L	0.096	0.375		0.021	0.297	0.016		0.033	0.045	0.097
Site × Q	0.052	0.376		0.027		0.020		0.097	0.044	0.127
					Seeding rate (Variance estimate)					
Site × I	5547	10104	198	62121375	0.380	328481	568	5.00	2705	4.71
Site × L	4.140	1.20 E–05	0.026	5913	4.96 E–05	21.700	0.003	5.94 E–04	0.008	0
					(Variance estimate *P* value)					
Site × I	0.032	–	0.031	0.022	0.029	0.017	0.014	0.038	0.057	0.035
Site × L	0.030	–	0.076	0.041	0.092	0.038	0.192	0.065	0.062	0.039
					N fertilizer rate (Variance estimate)					
Site × (I)	6740	6620			0.13	212107	2.82	364		3.43
Site × (L)	1.2e–18	0.723			0	12.0	0	0.001		0
Site × (Q)	–	–			–	–	–	–		–
					(Variance estimate *P* value)					
Site × (I)	0.015	0.027			0.03	0.014	0.022	0.01		0.026
Site × (L)	–	0.054			0.475	0.015	0.034	0.069		0.142
Site × (Q)	–	–			–	–	–	–		–

[z]Analysis results not included because variance estimate for this effect was either 0, NS, or caused model convergence issues.

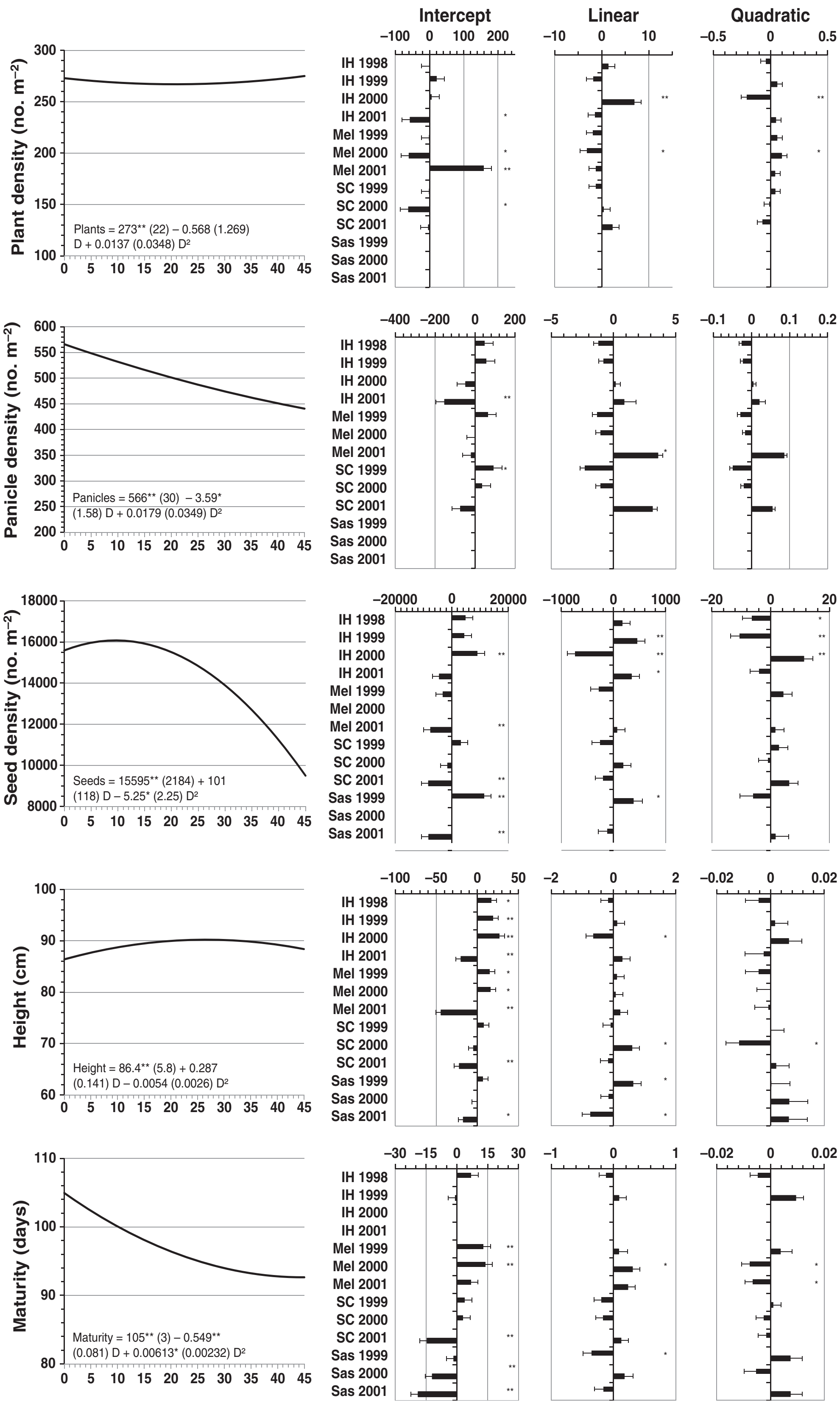

Fig. 1 (*Continued*)

The site × linear variance estimate indicates that the linear response of seed density to seeding date at several individual sites differed from estimated linear coefficient averaged over all sites (Table 4 and Fig. 1). In Fig. 1. the average linear coefficient is presented followed by the estimated deviation of each site year from the average linear coefficient. There was a larger decrease in seed density from the linear coefficient of the response curve as seeding was delayed at Indian Head in 2000, and a smaller decrease as seeding was delayed at Indian Head in 2001 and 1999 and at Saskatoon in 1999. The quadratic coefficient at the individual sites differed from the overall quadratic coefficient at three sites. The quadratic coefficients for individual sites was larger than the overall coefficient at Indian Head in 2000 and smaller than the overall coefficient at Indian Head in 1999 and 1998.

The linear and quadratic coefficients for the response of kernel weight to delayed seeding were not significant (data not shown). This lack of a seeding date effect on kernel weight was also reported in other studies (Miller 2000; Bodega et al. 2003). The intercept was 7.2 g 1000 kernels^{-1} and it ranged from 4.8 at Indian Head in 2000 to 8.0 at Saskatoon in 1999. These two sites were the only sites at which the site intercept differed from the overall intercept. The site × linear coefficient was not significant and the site × quadratic coefficient could not be estimated.

A 30- to 45-d delay in seeding had an impact on grain yield with the quadratic coefficient, site × intercept, site × linear and site × quadratic being significant but not the linear coefficient (Fig. 2 and Table 4). The quadratic coefficient of the response curve was −0.353 (Fig. 2). Grain yield was almost flat, going from 1141 to 1151 kg ha^{-1} as seeding was delayed from 0 to 15 d and then declined to 1003 kg ha^{-1} as seeding was delayed by 30 d. After seeding was delayed by 45 d the estimated yield was 696 kg ha^{-1}, a 40% decrease in yield from 15 d. Miller (2000) reported similar results with no significant decline as seeding was delayed from early to mid-May followed by a large decline as seeding was delayed to early June in one year and in the second year, grain yield declined every time seeding was delayed. A similar response has been observed in oat with a 65% decrease in yield (May et al. 2004a) and in barley with a 47% decrease in yield (Juskiw and Helm 2003). However, in barley and oat, grain yield started to decline as seeding was delayed from 0 to 15 d, while the grain yield of annual canarygrass in this study did not decline until after seeding was delayed for 15 d. This suggests that small delays in seeding annual canarygrass will not be as detrimental to grain yield as in other cereals. In addition, the coefficient of variation tended to increase as seeding was delayed suggesting that not only did yield decline as seeding was delayed but variability in yield increase (Fig. 3).

Since seeding date had little effect on plant density and kernel weight, a moderate effect on panicle density and a large effect on seed density, it appears that seed density was the yield component than was the most sensitive to seeding date. The changes in seed density then resulted in the observed changes in grain yield. However, Miller (2000) found with 2 site years of data that changes in panicle density were more consistent than changes in kernel density in predicting grain yield decline.

The overall intercept was 1141 kg ha^{-1} and it ranged from 569 kg ha^{-1} at Swift Current in 2001 to 2178 kg ha^{-1} at Saskatoon in 1999 and the intercept at individual sites significantly deviated from the overall intercept at 6 out of the 13 sites (Fig. 2). Compared with the overall intercept, the individual intercept was higher at three sites, Indian Head in 1999, Melfort in 2000 and Saskatoon in 1999 and lower at three sites, Melfort in 2001, Saskatoon in 2001 and Swift Current in 2001. As with seed density, the three sites with the lower site intercepts were the sites that had precipitation levels below the 30-yr average of each site (Table 3). The linear coefficient at the individual sites deviated from the overall linear coefficient at 5 of the 13 sites creating a significant site × linear interaction (Fig. 2 and Table 4). The quadratic coefficient at the individual sites deviated from the overall linear coefficient at 4 of the 13 sites creating a site × quadratic interaction (Fig. 2 and Table 4). As can be seen in Fig. 2, the shape of the yield curve varied among the sites with linear and or quadratic coefficients that differed from the overall coefficients, but the downward trend as seeding was delayed was consistent. The overall linear coefficient was not significant because the response of grain yield when seeding was delayed from 0 to 15 d varied widely with increases in grain yield at some sites and decreases at other sites. Most importantly, as seeding was delayed past 15 d to 30 and 45 d, grain yield consistently declined.

Fig. 1 (*Continued*). The effect of seeding date (D) on annual canarygrass development. X-axis for the chart to far left represents days after first seeding date. Regression equations include an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept, linear, and quadratic terms. For example, for IH 2000 plant density the linear slope coefficient is 6.87 units more than overall slope coefficient across sites (−0.58). Deviation charts were not included for those coefficients where site variability was zero or when that particular site by coefficient was not included. Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: $* = 0.05 \geq P$ value ≥ 0.01 and $** = P$ value < 0.01.

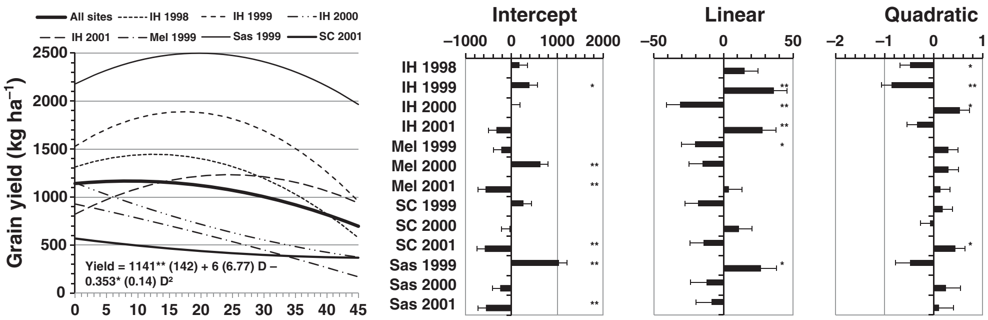

Fig. 2. The effect of seeding date (D) on annual canarygrass and yield. X-axis for the chart to far left represents days after first seeding date. The regression equation (all sites only) includes an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. Trend lines were also included for those sites with notably different responses. The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept, linear, and quadratic terms. For example, for IH 2000 the linear slope coefficient is 31 units less than overall slope coefficient across sites (6.00). Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * $= 0.05 \geq P$ value ≥ 0.01 and ** $= P$ value < 0.01.

These results indicate to growers that delays in seeding for up to15 d can be tolerated as they try to get all their crops seeding; however, delays beyond 15 d will likely result in significant decreases in grain yield.

The linear and quadratic coefficients for the response of height to delayed seeding were not quite significant and had similar *P* values ($P < 0.07$) (Fig. 1). The intercept, site × intercept and site × linear interactions were significant (Table 4). The intercept was 86 cm and it ranged from 113 cm at Indian Head in 2000 to 42 cm at Melfort in 2001 (Fig. 1). At 9 of the 13 sites, the intercepts at individual sites deviated from the overall intercept with five sites being higher and four lower than the overall intercept. This indicates that height in

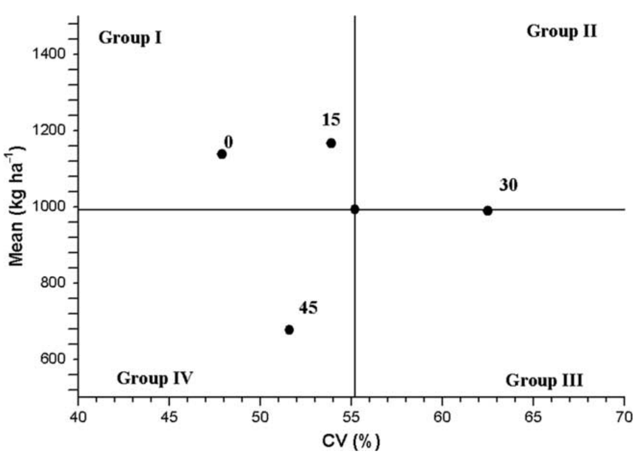

Fig. 3. Biplot of estimate means vs. coefficient of variation (CV) of seeding date for data collected from four sites in Saskatchewan from 1998 to 2001. The number of the data point represents the days seeding was delayed. Group I: High mean, low variability (optimal); Group II: High mean, high variability; Group III: Low mean, high variability (poor); Group IV: Low mean, low variability.

annual canarygrass was extremely sensitive to environmental conditions at the early seeding date. The linear coefficients significantly differed from the overall linear coefficient at 4 out of 13 site-years. The lack of significant linear and quadratic coefficients indicates that seeding date did not have a large impact on the height of annual canarygrass.

The days to maturity of annual canarygrass decreased as seeding was delayed, with both the linear, −0.549, and quadratic coefficients, 0.006, of the response curve being significant (Fig. 1). The intercept was 105 d and as seeding was delayed the maturity decreased to 92 d with a 45-d delay in seeding with the largest decrease coming between 0 and 15 d [days to maturity $= 105 + (-0.549 \times \text{days delayed}) + (0.006 \times \text{days delayed}^2)$]. The site × intercept, site × linear and site × quadratic interactions were all significant (Table 4). The overall intercept differed from the intercept at 5 out of 11 sites (Fig. 1). The individual site intercept was higher than the overall intercept at Melfort in 1999 and 2000 and lower at Swift Current in 2001 and at Saskatoon in 2000 and 2001. This is not surprising since Melfort tends to be cooler than Saskatoon and Swift Current. This can be seen by comparing the monthly average temperatures for 30 yr presented in Table 2. At three individual sites, Saskatoon in 2001, Melfort in 2000 and 2001, the linear coefficient for the response of maturity to seeding date differed from the overall linear coefficient. The quadratic coefficient for the response of maturity to seeding date at Indian Head in 1999, Melfort in 2000 and 2001, differed from the overall quadratic coefficient.

The effect of delayed seeding on test weight was limited to a significant site and site × intercept interaction (Table 4). The overall intercept was 67.3 kg hL^{-1} and the intercept ranged from 58.3 kg hL^{-1} at Swift Current in 2000 to 72.5 kg hL^{-1} at Saskatoon in 2001.

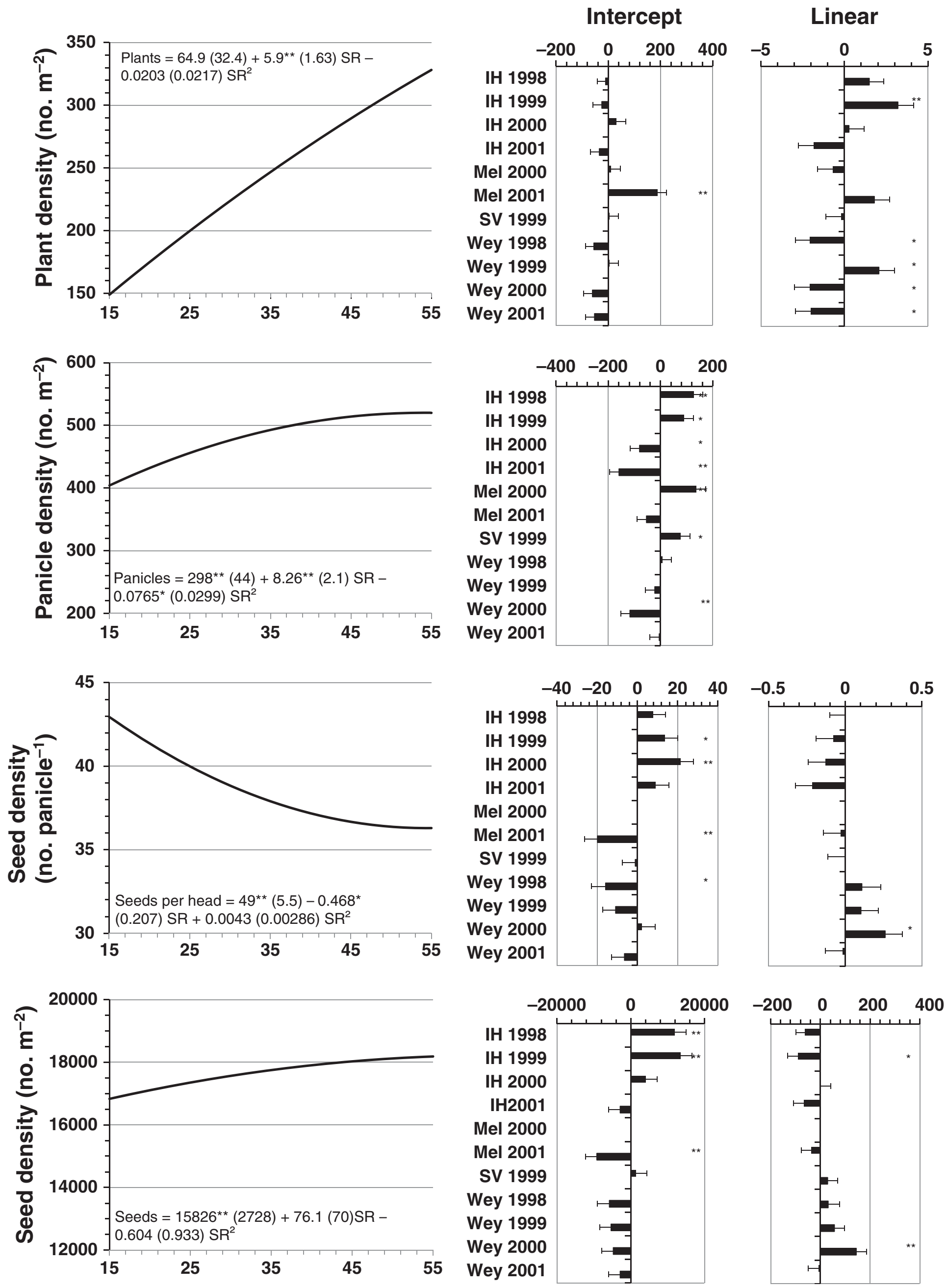

Fig. 4. The effect of seeding rate (SR) on annual canarygrass grain yield development. X-axis for the chart to far left represents annual canarygrass seeding rate (kg ha^{-1}). Regression equations include an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. The three charts on the right represent the difference deviation) between regression coefficient estimates across sites relative to a given site for the intercept, linear, and quadratic terms. For example, for IH 2000 plant density the linear slope coefficient is 1.12 units more than overall slope coefficient across sites (5.86). Deviation charts were not included for those coefficients where site variability was zero or when that particular site by coefficient was not included. Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * $= 0.05 \geq P$ value ≥ 0.01 and ** $= P$ value < 0.01.

In addition to these two sites, the site intercepts differed from the overall intercept at two additional sites, 59.5 kg hL^{-1} at Indian Head in 2000, and 72.1 kg hL^{-1} at Saskatoon in 1999. The stability of test weight as seeding was delayed in annual canarygrass is quite different from the response seed in oats and barley where test weight decreased as seeding is delayed (Juskiw and Helm 2003; May et al. 2004a).

Seeding Rate

Seeding rate had a significant effect on the linear or quadratic response coefficients of plant density, panicle density, grain yield and height (Fig. 4). The linear coefficient and the site × intercept and site × linear interactions all had an effect on plant density (Fig. 4 and Table 4). As seeding rate increased, plant density, as expected, increased with a linear coefficient of 5.9 and plant density increased from 149 plants m^{-2} at 15 kg ha^{-1} to 329 plants m^{-2} with 55 kg ha^{-1} [plant density $= 64 + (5.9 \times \text{seed rate}) + (-0.020 \times \text{seed rate}^2)$]. The linear coefficients at the individual sites differed from the overall linear coefficient at 5 out of 11 sites (Fig. 4). At Indian Head and Weyburn in 1999, the plant density increased at a faster rate than the overall average of all sites, while at Weyburn in 1998, 2000 and 2001 the plant density increased at a slower rate. The overall intercept was 65 plants m^{-2} and the site intercept at Melfort in 2000, 254 plants m^{-2}, was the only site intercept that differed from the overall intercept.

Panicle density was affected by the linear coefficient, and quadratic coefficient. The intercept was 298 panicles m^{-2} with a linear coefficient of 8.3 and a quadratic coefficient of −0.077 (Fig. 4). There was a gradual increase in panicle density as the seeding rate increased from 405 panicles m^{-2} at 15 kg ha^{-1} to 516 panicles m^{-2} at 45 kg ha^{-1} and then leveling off to 521 panicles m^{-2} at 55 kg ha^{-1} seeding rate. This indicates that annual canarygrass could not produce enough tillers at the lower seeding rates to completely compensate for the lower plant densities at the lower seeding rates. Similar results have been found in oat (May et al. 2009b), common wheat and barley (Lafond 1994). The individual site intercepts ranged from 431 to 142 panicles m^{-2}, but on an individual basis none of the site intercepts significantly deviated from the overall intercept (Fig. 4). A *P* value could not be estimated for the site × linear coefficient and the site × quadratic coefficient was not significant (Table 4).

Seeds per panicle decreased linearly as seeding rate increased (Fig. 4). The decrease in seeds per panicle was compensated by an increase in panicles per meter, the end result being no change in the number of seeds per meter as seeding rate increased (Fig. 4). There was a significant site × intercept interaction with 4 out of 11 site intercepts being different than the overall intercept (Fig. 4 and Table 4).

Kernel weight had a significant site × intercept interaction, but the overall linear and quadratic coefficients were not significant (Table 4). Holt (1989) also found that seeding rate had no effect on the kernel weight of annual canarygrass. A similar response was observed in oat (May et al. 2009b); however, a significant decrease in kernel weight from increasing the seeding rate has been found in common wheat and barley (Lafond 1994; O'Donovan et al. 2012). The intercept was 6.8 g 1000 $kernels^{-1}$ and the individual site intercepts ranged from 5.9 g 1000 $kernels^{-1}$ at Indian Head in 1999 to 7.6 g 1000 $kernels^{-1}$ at Indian Head in 2000, the individual site intercepts at these two sites along with the site intercepts of 6.0 g 1000 $kernels^{-1}$ at Weyburn in 2000 and 7.4 g 1000 $kernels^{-1}$ at Weyburn in 2001 significantly deviated from the overall intercept.

The linear coefficient, quadratic coefficient, site × intercept and site × linear were all significant for grain yield (Fig. 5 and Table 4). The intercept was 1078 kg ha^{-1} with a linear coefficient of 10.4 and a quadratic coefficient of −0.117 (Fig. 5). The response curve was very shallow, peaking at approximately 1310 kg ha^{-1} with a 45 kg ha^{-1} seeding rate. This response is supported by Holt (1989) who found a small quadratic increase in grain yield as the seeding rate increased from 7.5 to 80 kg ha^{-1} at Indian Head. In Holt's research, most of the increase in grain yield, 200 kg ha^{-1}, occurred as the seeding rate increased from 7.5 to 20 kg ha^{-1} and yield peaked at approximately 40 kg ha^{-1} there was very little change in grain yield as the seeding rate increased from 20 to 80 kg ha^{-1}. In addition, seeding rates of approximately 35 to

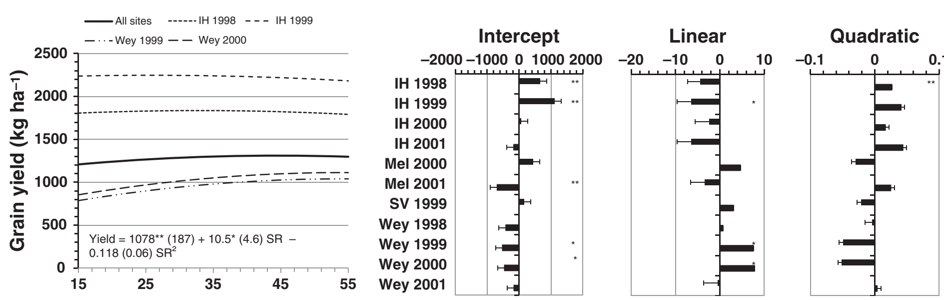

Fig. 5. The effect of seeding rate (SR) on annual canarygrass yield. X-axis for the chart to far left represents annual canarygrass seeding rate (kg ha^{-1}). The regression equation includes an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. Trend lines were also included for those sites with notably different responses. The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept, linear, and quadratic terms. For example, for IH 2000 the linear slope coefficient is 2.4 units less than overall slope coefficient across sites (10.5). Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * = 0.05 ≥ *P* value ≥ 0.01 and ** = *P* value < 0.01.

66 kg ha^{-1} had no effect on grain yield in Minnesota (Putnam et al. 1990). In other cereal crops a similar increase in grain yield of 200 to 400 kg ha^{-1} from increasing seeding rates has been reported (Lafond 1994; McKenzie et al. 2005; May et al. 2009b; O'Donovan et al. 2012). The coefficient of variation for grain yield tended to decrease as the seeding rate increased from 15 to 55 kg ha^{-1} (Fig. 6). This indicates that as the seeding rate increased the yield stability tended to increase. Therefore, there may be a small benefit to growers using higher seeding rates in annual canarygrass; however, seeding rate is definitely not an important source of yield variability in annual canarygrass.

The site × intercept interaction was significant (Table 4) and ranged from 371 kg ha^{-1} at Melfort in 2001 to 2196 kg ha^{-1} at Indian Head in 1999 (Fig. 5). Six of the 11 sites had intercepts that significantly deviated from the overall site intercept. The fact that over 50% of the sites have an intercept that is significantly high or lower than the average intercept is a strong indication of the large impact environmental conditions have on annual canarygrass yield at low seeding rates. The fact that the linear coefficient only differed at three individual sites, Indian Head in 1999, Weyburn in 1999 and 2000, from the overall linear coefficient indicates that increasing the seeding rate often could not overcome the environmental impact on grain yield that occurred at low seeding rates. At Weyburn in 1999 and 2000, the linear coefficient was larger than the overall coefficient. The site intercepts at these locations were lower than the overall intercept and grain yield had the strongest response to seeding rate at these two sites (Fig. 5). These two sites demonstrate the small benefit that can be gained from higher seeding rates; however, this benefit was only observed 18% of the time. At Indian Head in 1999, which had a higher site intercept than the overall intercept, the linear coefficient was smaller than the overall coefficient and grain yield stayed the same or decreased as the seeding rate increased.

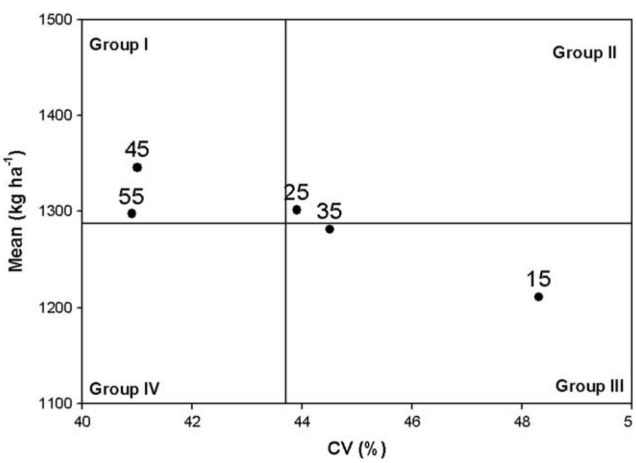

Fig. 6. Biplot of estimate means vs. coefficient of variation (CV) of seeding rate for data collected from four sites in Saskatchewan from 1998 to 2001. The number of the data point represents the days seeding was delayed. Group I: High mean, low variability (optimal); Group II: High mean, high variability; Group III: Low mean, high variability (poor); Group IV: Low mean, low variability.

Height was affected by the seeding rate resulting in a significant linear coefficient, quadratic coefficient, and site × intercept interaction. The intercept was 94.7 cm with a linear coefficient of 0.271 and a quadratic coefficient of −0.00427 of the response curve (Fig. 7). There was a very small increase in height of approximately 1 cm as the seeding rate increased from 15 to 32 kg ha^{-1}. As the seeding rate increase to 55 kg ha^{-1}, there was a 2-cm decrease in the height of the annual canarygrass (plant density = 94.7 + (0.271 × seed rate) + (−0.00427 × seed rate^2)). Holt (1989) found a linear instead of a curvilinear response with height decreasing from 95 to 91 cm as the seeding rate increased. The individual site intercepts ranged from 123 to 42 cm, and the individual site intercepts deviated from the overall intercept at 4 out of 11 sites (Fig. 7 and Table 4). This large variation in height at a specific site year indicates that environmental conditions can have a much larger impact on the height of annual canarygrass than seeding rate. Therefore, producers cannot use seeding rate to control the height of their annual canarygrass.

The site × seeding rate interaction for lodging was significant (Table 4). The intercept was 2.6 and the individual site intercepts ranged from 0.5 to 7.1. The lodging rating of 7.1 occurred at Melfort in 2000 and it had the only individual site intercept to deviate from the overall intercept. This site received some hail during the growing season. This indicates that the seeding rate used by producers will not affect the amount of lodging that occurs in their fields.

Maturity had a significant intercept but the linear (P value = 0.053) and quadratic coefficients were not significant (Fig. 7). The trend was for maturity to decrease by approximately 2 d as the seeding rate increased. Holt (1989) reported a similar trend that was not statistically significant. This indicates that producers may be able to hasten maturity in their annual canarygrass fields with increased seeding rates by a few days.

The site × intercept and site × linear coefficient were significant for test weight (Table 4). The intercept was 67.4 kg hL^{-1} and the individual site intercepts ranged from 63.5 to 70.2 kg hL^{-1}, and 3 out of 10 individual site intercepts significantly deviated from the overall intercept (Fig. 7).

Nitrogen Fertilizer

Panicle density, height, grain yield and test weight all responded to increasing nitrogen fertilizer rates, while, plant density, heading, kernel weight, maturity and lodging did not (Fig. 8). Although the decrease in plant density as the nitrogen rate increased was not statistically significant it is similar to other crops when seeded

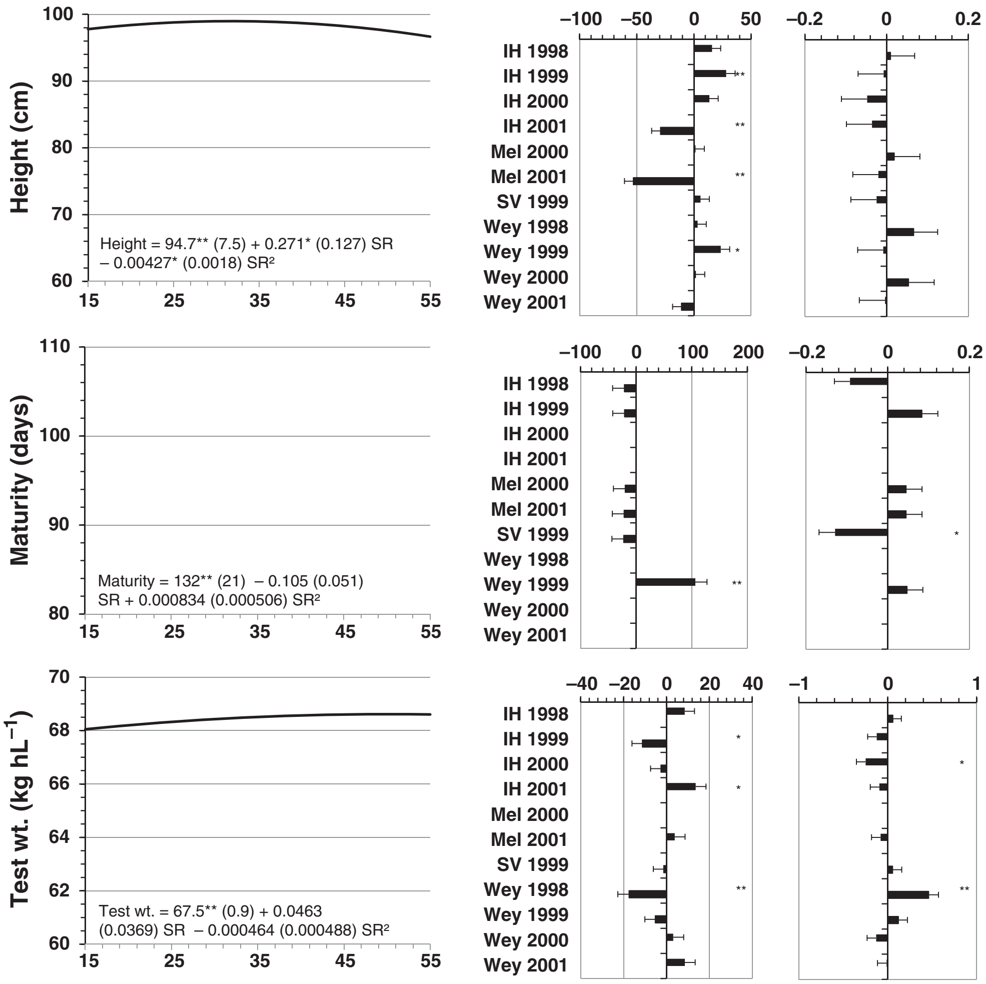

Fig. 7. The effect of seeding rate (SR) on annual canarygrass development. X-axis for the chart to far left represents annual canarygrass seeding rate (kg ha^{-1}). Regression equations include an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept, linear, and quadratic terms. For example, for IH 2000 plant density the linear slope coefficient is 1.12 units more than overall slope coefficient across sites (5.86). Deviation charts were not included for those coefficients where site variability was zero or when that particular site by coefficient was not included. Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * $=0.05 \geq P$ value ≥ 0.01 and ** $= P$ value <0.01.

in a no-till cropping system on the northern great plains of North America. Small reductions in plant density have been reported with a 3% decrease in oats (May et al. 2004b), a 7% decrease in Barley (O'Donovan 2011), a 10% decrease in durum wheat (*Triticum turgidum* L. var. *durum*) (May et al. 2008), a 10% decrease in *Brassica napus*, flax, *Brassica juncea* L. and sunflower (*Helianthus annuus* L.) (May et al. 2009a). However, no nitrogen effect on plant density was observed in spring wheat (*Triticum aestivum* L.) (Mooleki et al. 2010). The site × intercept interaction was significant with an overall intercept of 230 plants m^{-2} and a range of 347 plants m^{-2} at Indian Head in 1998 to 133 plants m^{-2} at Weyburn in 2000 (Fig. 8 and Table 4). The site intercepts significantly deviated from the overall intercept at Indian Head and Weyburn in all 4 yr (Fig. 8). The site intercept at Indian Head was higher than the overall intercept in 1998, 1999 and 2000, while at Weyburn the site intercept was lower than the overall intercept in 1998, 2000 and 2001. This indicates that side banded nitrogen rate did not have a large effect on seedling emergence while environmental conditions at specific sites can have a large impact on seedling emergence.

For panicle density, both the linear, 1.9, and quadratic coefficients, −0.01, of the response curve were significant with panicle density estimated from the curve to peak at 507 panicles m^{-2} with 70 kg ha^{-1} of fertilizer nitrogen (Fig. 8). The site × intercept interaction variance estimate was significant for panicle density

(Table 4). The intercepts ranged from 292 panicles m^{-2} at Indian Head in 2001 to 586 panicles m^{-2} at Stewart Valley in 2001, and these two individual site intercepts were the only site intercepts to significantly deviated from the overall intercept (Fig. 8). The site × linear slope coefficient variance estimate was not significant (Table 4). It is interesting to note that panicle density appears to be less sensitive to environmental conditions than plant density with only 2 site years being different from the overall average compared with 5 site years for plant density.

The linear and quadratic coefficients for the response of kernel weight to N fertilizer were not significant (Fig. 8). Holt (1988) also found that kernel weight was not affected by the application of fertilizer. This indicates that panicle density was the main yield component affected by nitrogen. The site × intercept variance estimate for kernel weight was significant indicating that the environment affected kernel weight among sites at the lowest nitrogen rate (Table 4). The site × linear variance estimate was not significant indicating that the environment did not interact with the effect of nitrogen rate on kernel weight (Table 4). The significant site × intercept variance estimate corresponded with intercepts that ranged from 8.0 g 1000 kernels^{-1} at Indian Head in 1999 to 6.8 g 1000 kernels^{-1} at Weyburn in 2000, and 4 out of 12 sites, including the two sites just mentioned had site intercepts that significantly deviated from the overall intercept (Fig. 8).

Grain yield was affected by the application of nitrogen with significant linear, 3.73, and quadratic coefficients, −0.024 (Fig. 9). The response was not large. The response curve estimates that a maximum yield of 1216 kg ha^{-1} was obtained at a nitrogen rate of 78 kg ha^{-1}. The yield at 20 kg ha^{-1} was 1136 kg ha^{-1} resulting in a 1.3 kg ha^{-1} increase in grain yield for each kilogram of actual fertilizer N added. The majority of the increase in grain yield occurred between the 20 and 40 kg ha^{-1} N rates with a 2.3 kg ha^{-1} increase in grain yield for each kilogram of fertilizer N added between 20 and 40 kg ha^{-1}. There was small increase in the yield stability as the nitrogen rate increased from 20 to 40 kg ha^{-1}; however, as the nitrogen rate increased above 40 kg ha^{-1} an increase in seed yield was noted as well as increased variation (Fig. 10). Therefore, not only was the grain yield increase above 40 kg ha^{-1} small it became more variable further reducing the incentive to growers to use N rates above 40 kg ha^{-1}. Annual canarygrass with less than a 150 kg ha^{-1} increase in grain yield appears to be less responsive to N than most other cereal crops with a 800 kg ha^{-1} increase reported in oat (May et al. 2004b) and a 1200 and 1400 kg ha^{-1} increase in barley (McKenzie et al. 2005; O'Donovan et al. 2011). A further analysis was carried out for grain yield combining the fertilizer N and the residual N in the soil for each site. The following equation was derived with the intercept and both coefficients were significant. Grain yield $= 915 + [5.47 \times (\text{N rate} + \text{soil N})] + [-0.024 \times (\text{N rate} + \text{soil N})^2]$ (Fig. 9). There was not a great change in the response curve. The curve was just moved to the right on the X axis.

In this study the increase in grain yield from N fertilizer, approximately 7%, is similar to the response observed by Dr. R.G. Robinson in Minnesota, where only 1 out of 4 site years found a significant response from N fertilizer (Putnam et al. 1990). In contrast, Holt (1988) found a 27% increase in grain yield at Indian Head, SK, when the N fertilizer rate was increased from 25 to 100 kg ha^{-1}. The reduced response at Indian Head observed in this study may be due to changes in cropping practices such as the introduction of no-till seeding and increased rates of fertilizer N used in other crops. The highest grain yields did not differ greatly between the two studies, with Holt (1988) reporting 1270 kg ha^{-1} as the highest yield, and in this study yield peaked at 1216 kg ha^{-1}. Fertilizer recommendations published by the North Dakota State University Extension Service suggested that for a yield goal of 1300 kg ha^{-1}, 50 kg ha^{-1} of a combination of soil residual N and fertilizer N should be used (Putnam et al. 1996). This recommendation in most cases would be similar to or lower than the 40 kg ha^{-1} of fertilizer N, regardless of the soil N suggested by this study.

The site × intercept and site × linear interaction variance estimates were significant (Table 4). The significant site × intercept variance estimate corresponded with intercepts that ranged from 21 46 kg ha^{-1} at Indian Head in 1999 to 543 at Stewart Valley in 2001, and 5 out 12 sites had intercepts that deviate from the overall intercept (Fig. 9). The site × linear coefficient deviated from the overall linear coefficient at two sites, Indian Head in 2001 and Stewart Valley in 2000. The linear coefficient at Indian Head in 2001 was 0.65 indicating that at this site there was almost no yield response to N fertilizer (Fig. 9). The linear coefficient at Stewart Valley in 2000 was 12.96 and the response to N was much larger at this site than any other site in the study (Fig. 9). Interestingly, this site year had a soil N residual level of 31 kg ha^{-1}. There were several site years with similar or lower soil N levels that did not have such a large response to nitrogen fertilizer. In addition, the higher yield response at Stewart Valley could not be attributed to precipitation or temperature since both were near the 30-yr average. At the site year with a response below the overall linear coefficient, Indian Head in 2001, the residual N level was 45 kg N ha^{-1}, was similar to other site years that did not deviate from the overall linear coefficient. In this study the residual level of N in the soil did not appear to have a large impact on the response of annual canarygrass to N. This is not surprising since the overall response of annual canarygrass to N fertilizer was not very large.

Lodging was not affected by the application of nitrogen fertilizer to any great extent in this study (Fig. 8) but the site × intercept and site × linear variance

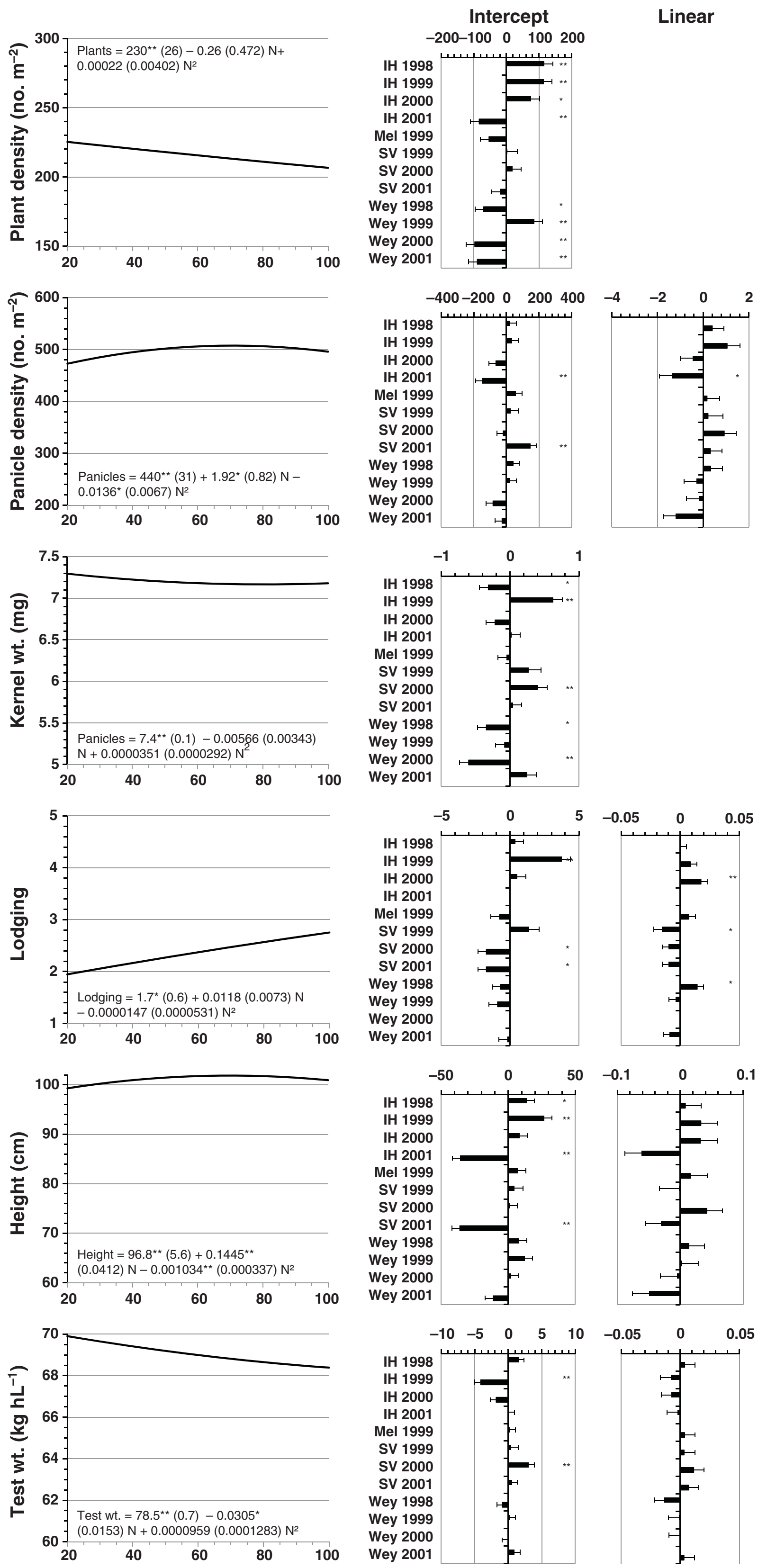

Fig. 8 (*Continued*)

estimates were significant (Table 4). The overall lodging intercept was 1.72 and the individual site intercepts ranged from 0 at Stewart Valley in 2000 to 5.2 at Indian Head in 1999 (Fig. 8). The site intercept at three sites, Indian Head in 1999 and Stewart Valley in 2000 and 2001 deviated from the overall intercept. No lodging occurred at Stewart Valley in 2000 and 2001. The significant site × linear variance estimates indicates that the effect of N deviated from overall effect at some sites (Table 4). At Indian Head in 2000 and Weyburn in 1998 the linear response to N was larger than the overall estimated linear response (Fig. 8). Interestingly these two sites had the lowest level of residual N of all the sites in the study. However, more data would be required before it can be assumed that low levels of residual soil N in the spring predispose annual canarygrass to lodging. At Stewart Valley in 1999, the linear response to N was lower than the overall estimated linear response.

The application of N had a small effect on plant height. The intercept, 96.8, and the linear, 0.14, and quadratic coefficients, −0.001, of the response curve were all significant (plant height = 96.8 + (0.14 × N rate) + (−0.001 × N rate^2), with height estimated to peak at 101.7 cm with 70 kg ha^{-1} of applied nitrogen (Fig. 8). Holt (1988) reported a similar quadratic increase in plant height, although, the overall heights obtained in that study were shorter with plant height peaking at 88 cm with 100 kg ha^{-1} of applied nitrogen. The site × intercept interaction variance estimate was significant for height (Table 4). The intercepts ranged from 60.6 cm at Stewart Valley in 2001 to 123.4 cm at Indian Head in 1999, and 4 out of 12 site intercepts deviated from the overall intercept (Fig. 8). This indicates that the environment has a much larger impact on height than N and, in addition, that the heights reported by Holt (1988) were well within the range of heights observed in this study at various locations. The site × linear slope coefficient variance estimate was not significant.

Increasing the N rate decreased the test weight of annual canarygrass. The intercept, 70.5 kg hL^{-1} and the linear coefficient, −0.0304, of the response curve were significant [test weight = 70.5 + (−0.0304 × N rate) + (0.000096 × N rate^2)] with the test weight decreasing from 69.9 to 68.4 kg hL^{-1} as the N rate increased from 20 to 100 kg ha^{-1} (Fig. 8). A similar response was reported by Holt (1988) who found that the test weight decreased from 61.6 to 60.8 kg hL^{-1} as the N fertilizer rate increased from 25 to 100 kg ha^{-1}. This decrease does not appear to be of biological or economic significance. The site × intercept interaction variance estimate was significant for test weight (Table 4). The intercepts ranged from 73.5 kg hL^{-1} at Stewart Valley in 2000 to 66.4 kg hL^{-1} at Indian Head in 1999, and site intercepts at these two locations deviated from the overall intercept (Fig. 8). The effect of environment on test weight was much greater than the effect of N on test weight. The site × linear slope coefficient variance estimate was not significant.

CONCLUSIONS

A nitrogen fertilizer effect on grain yield of annual canarygrass was observed but the increases were small. A maximum yield of 1216 kg ha^{-1} was obtained at a nitrogen rate of 78 kg ha^{-1} with the majority of the increase occurring between the 20 and 40 kg ha^{-1} N rates. In addition seed yield stability appeared to decrease above 40 kg ha^{-1} of N. This indicates that there would be little incentive for annual canarygrass producers to use N fertilizer rates above 40 kg ha^{-1}. As seeding rate increased there was a small but significant increase in the grain yield of annual canarygrass peaking at approximately 1310 kg ha^{-1} with 45 kg seed ha^{-1}. In addition, yield stability tended to increase as seeding rate increased. This indicates that producers should increase their seeding rate to 45 kg ha^{-1} to maximize grain yield and yield stability. The changes in grain yield caused by seeding rate, or nitrogen rate, were not large enough to account for large variations in grain yield observed between site years. The high percentage of sites intercepts deviating from the overall intercept for seeding rate and nitrogen rate indicate that the environment had a large impact while the low number of significant site × linear interactions signifies that usually the environment did not interact with seeding rate or nitrogen rate.

Delaying seeding for 15 d to the middle of May had very little effect on seed yield, but delayed seeding beyond the middle of May resulted in important yield reductions and should be avoided as much as possible. Seeding date was shown to reduce seed yield variability between sites but not enough to explain the large variations between site years even when appropriate seeding dates were used. Therefore, further research is required to identify the causes of high seed yield

Fig. 8 (*Continued*). The effect of N fertilizer rate (N) on annual canarygrass development. X-axis for the chart to far left represents N fertilizer rate (kg N ha^{-1}). Regression equations include an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept and linear terms. For example, for IH 2000 plant density the linear slope coefficient is 0.042 units less than overall slope coefficient across sites (−2.60). Deviation charts were not included for those coefficients where site variability was zero or when that particular site by coefficient was not included. Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * = 0.05 ≥ P value ≥ 0.01 and ** = P value < 0.01.

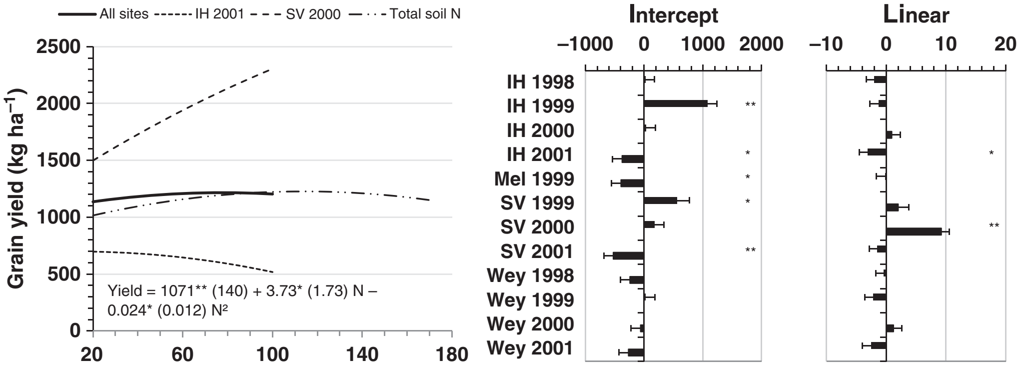

Fig. 9. The effect of N fertilizer rate (N) on annual canarygrass and yield. X-axis for the chart to far left represents N fertilizer rate (kg N ha^{-1}). The regression equation includes an intercept, linear, and quadratic (curvilinear) slope coefficient estimates and corresponding SE in parentheses. Trend lines were also included for those sites with notably different responses and for the regression against total soil N (residual soil N plus N fertilizer rate). The three charts on the right represent the difference (deviation) between regression coefficient estimates across sites relative to a given site for the intercept and linear terms. For example, for IH 2000 the linear slope coefficient is 0.93 units more than overall slope coefficient across sites (3.73). Abbreviations for locations are defined in Table 1a. Deviation chart error bars are SE. The statistical significance of regression coefficients and deviations are indicated as follows: * $= 0.05 \geq P$ value ≥ 0.01 and ** $= P$ value < 0.01.

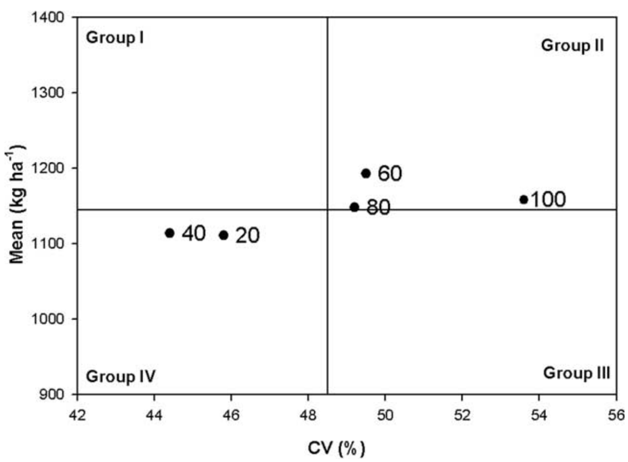

Fig. 10. Biplot of estimate means vs. coefficient of variation (CV) of nitrogen rate for data collected from four sites in Saskatchewan from 1998 to 2001. The number of the data point represents the days seeding was delayed. Group I: High mean, low variability (optimal); Group II: High mean, high variability; Group III: Low mean, high variability (poor); Group IV: Low mean, low variability.

variability in annual canarygrass. In conclusion, it is recommended that farmers use a seeding rate of 35 to 45 kg ha^{-1}, a nitrogen rate of approximately 40 kg ha^{-1} and seed in early to mid-May.

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